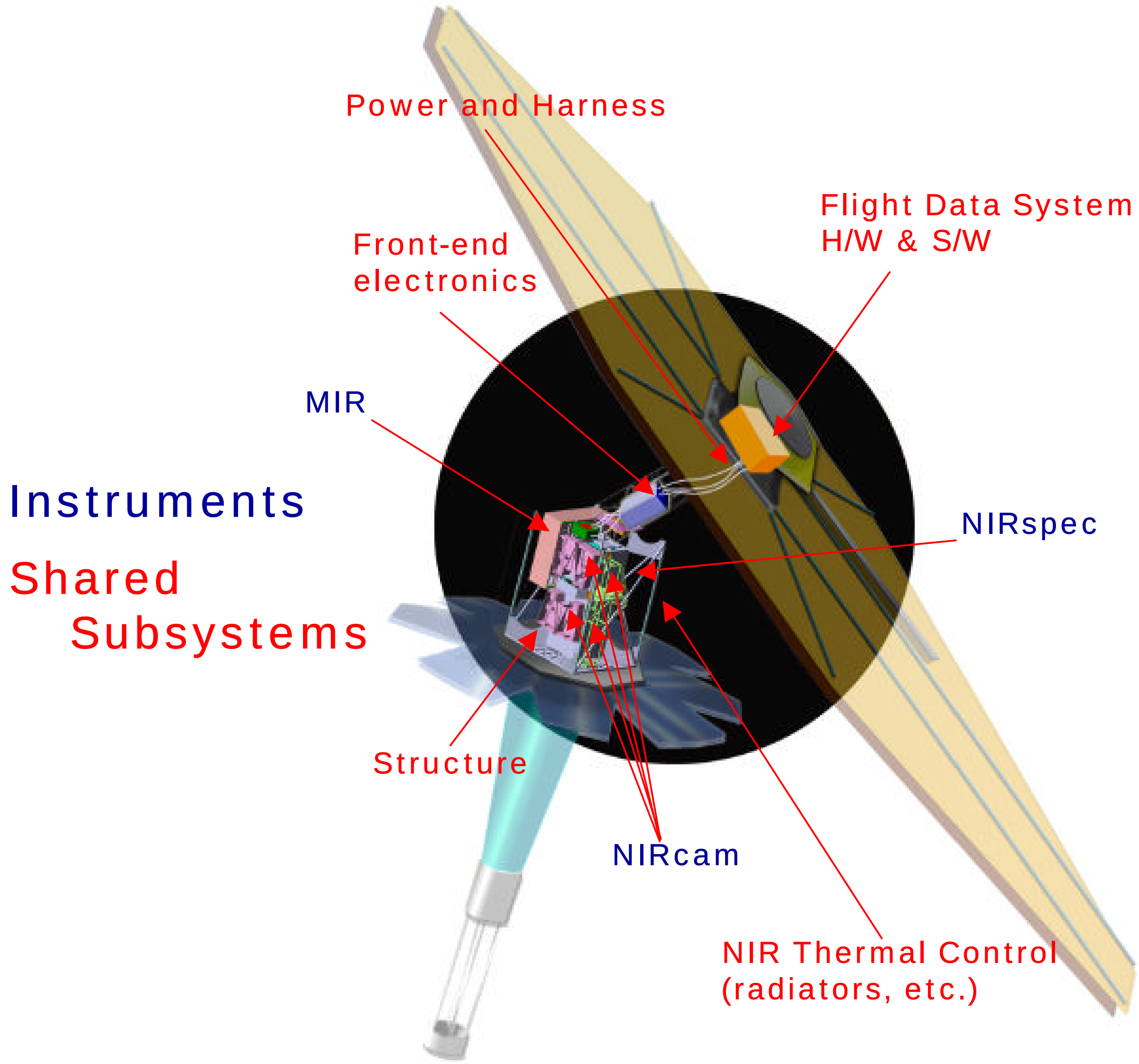
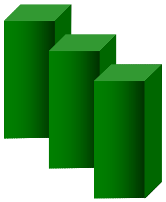
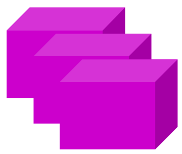
ISIM is the Payload of NGST

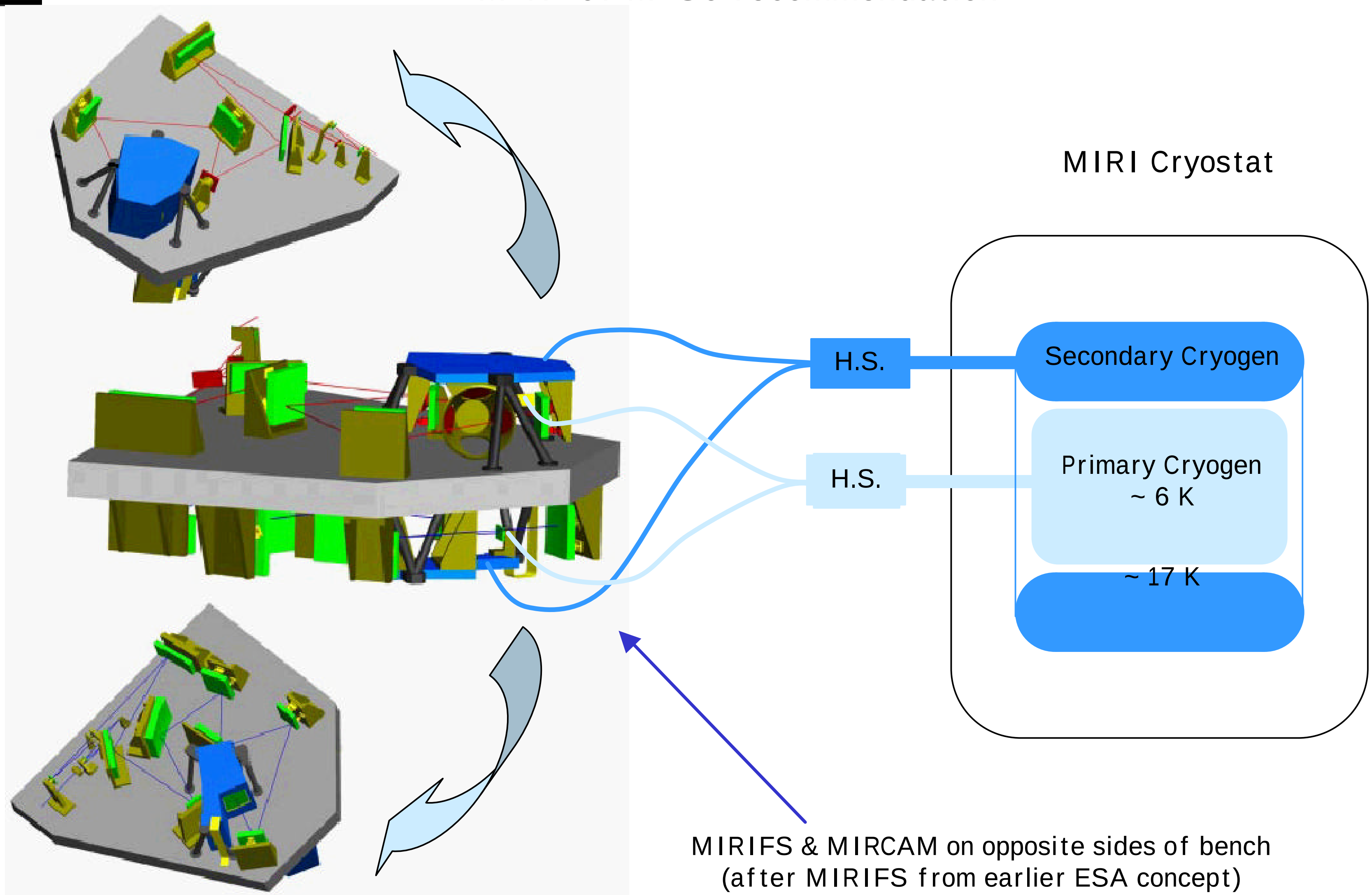




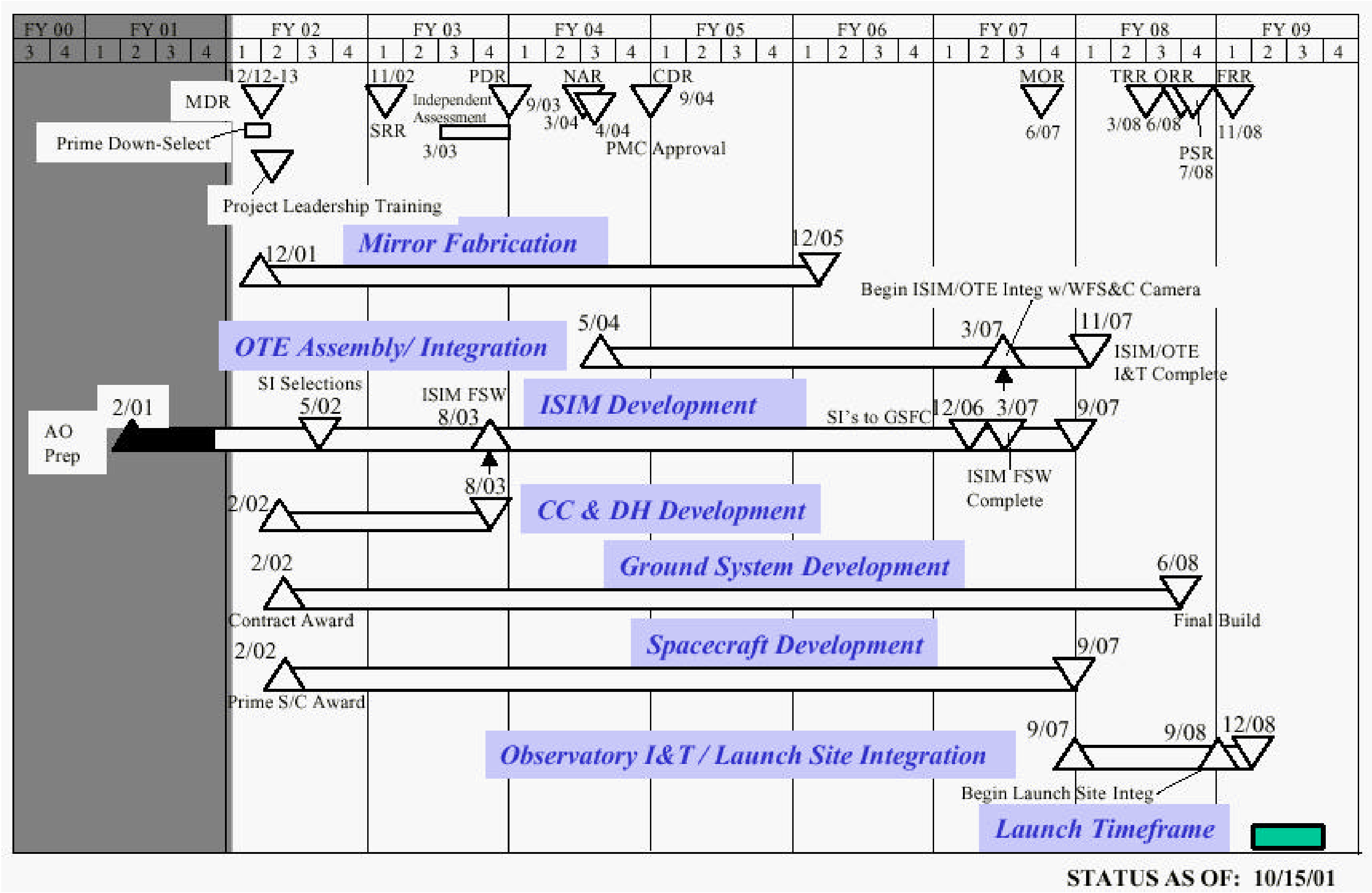


MIRI Cooling

MIRI of MISC recommendation

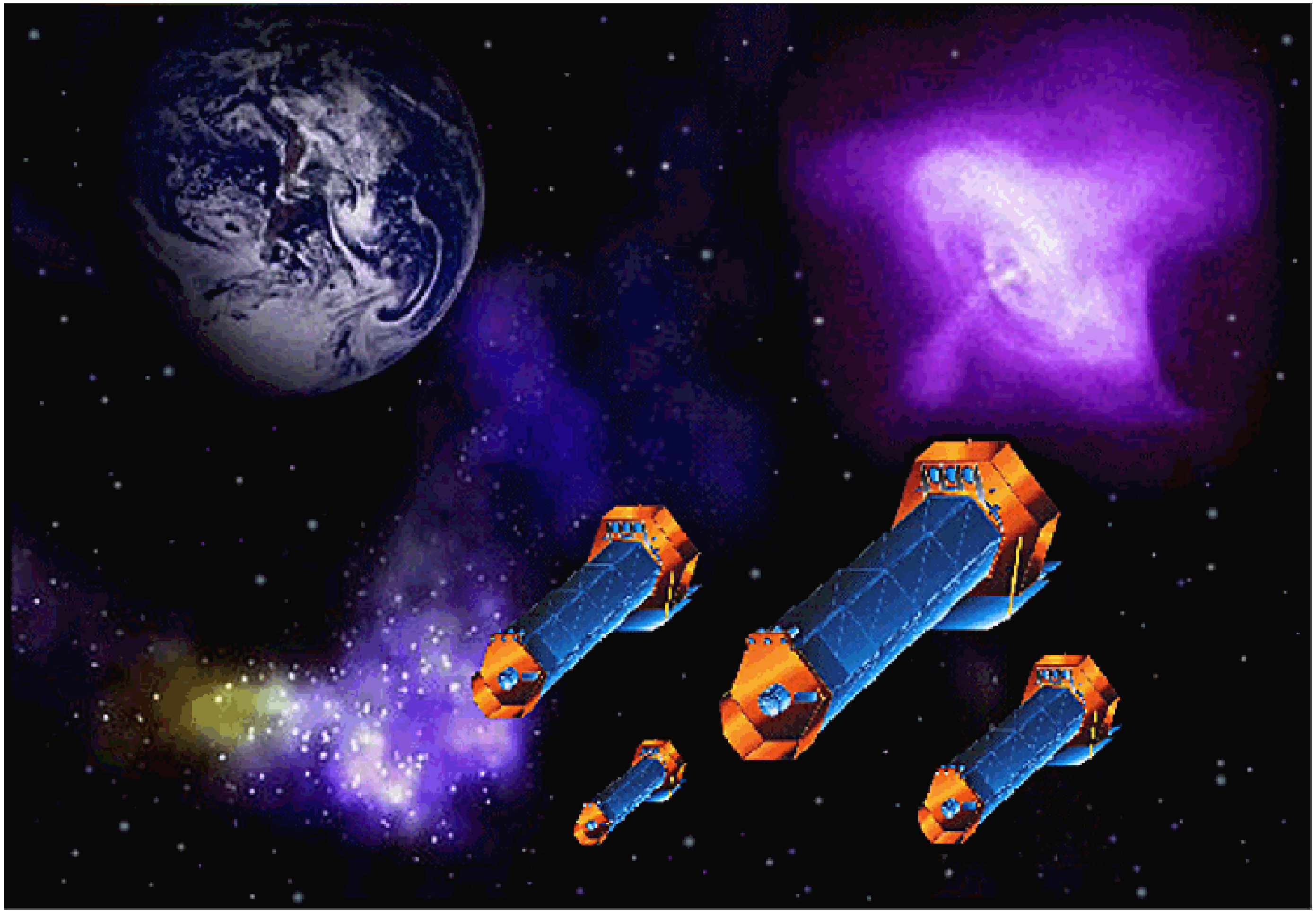


NGST Top Level Observatory Schedule



Stay up to date at: http://ngst.gsfc.nasa.gov

Constellation X-ray Mission



Govind Gadwal

Goddard Space Flight Center

http://constellation.gsfc.nasa.gov

Roadmap to Image a Black Hole

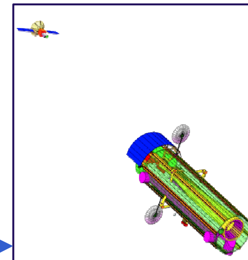
Imaging

Chandra

0.5 arc sec

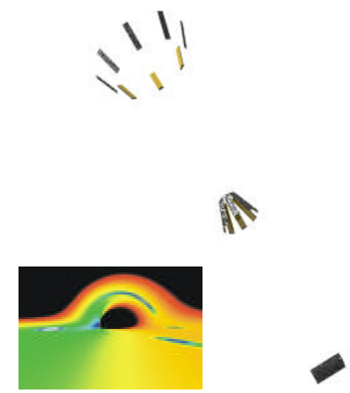
Optimize MAXIM Parameters

1000 times finer imaging



MAXIM Pathfinder

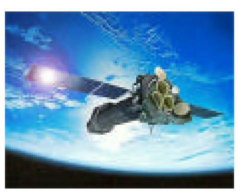
10 Million times finer imaging



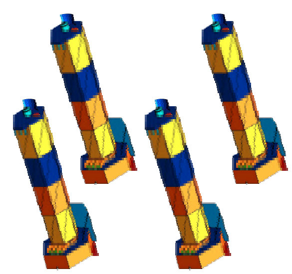
MAXIM

Spectroscopy

XMM



Constellation-X



100 times larger area

Find them

Conditions in the inner disk

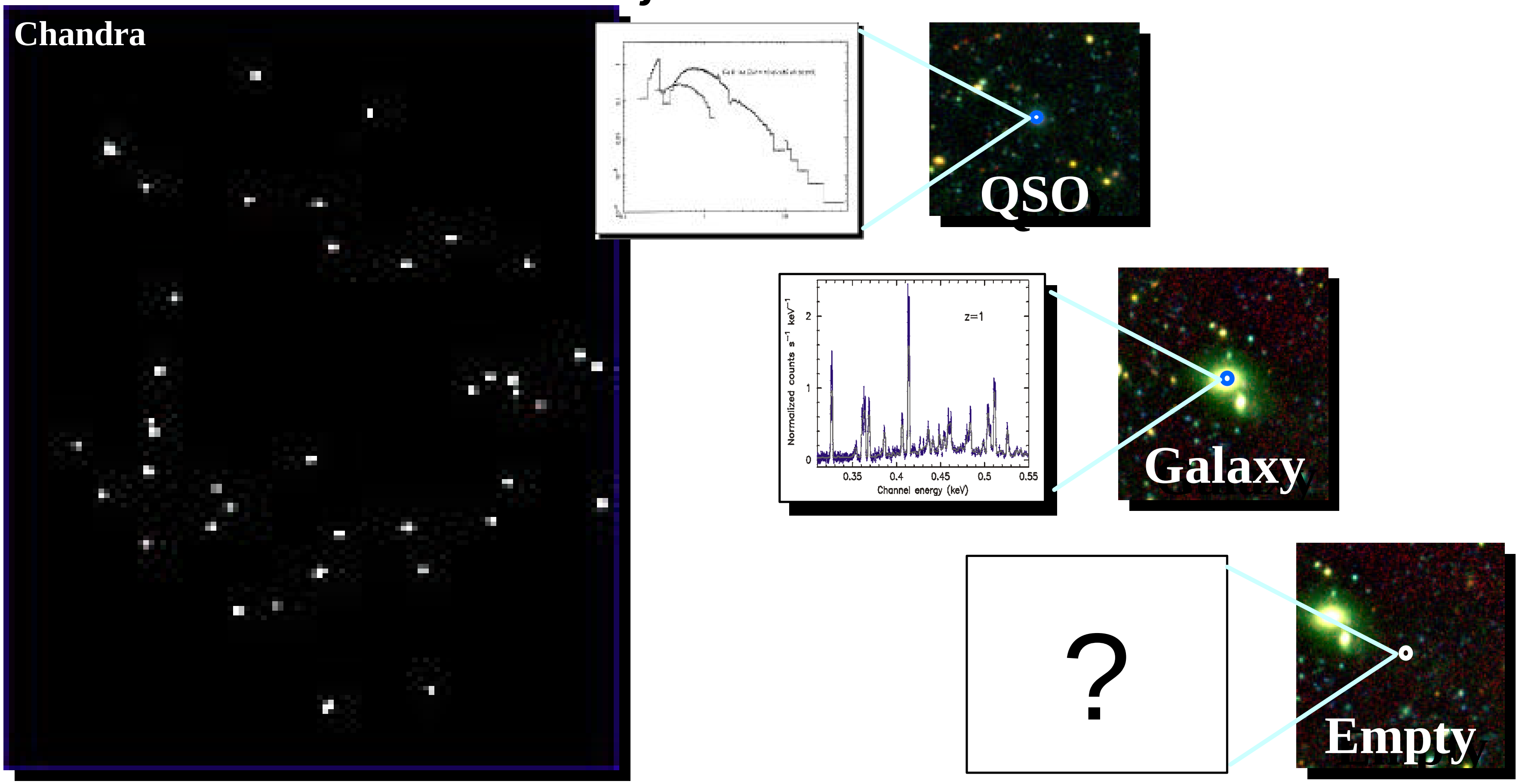
X-ray interferometry first flight

Black hole imager!

2000 *2010* *2014* *2020*

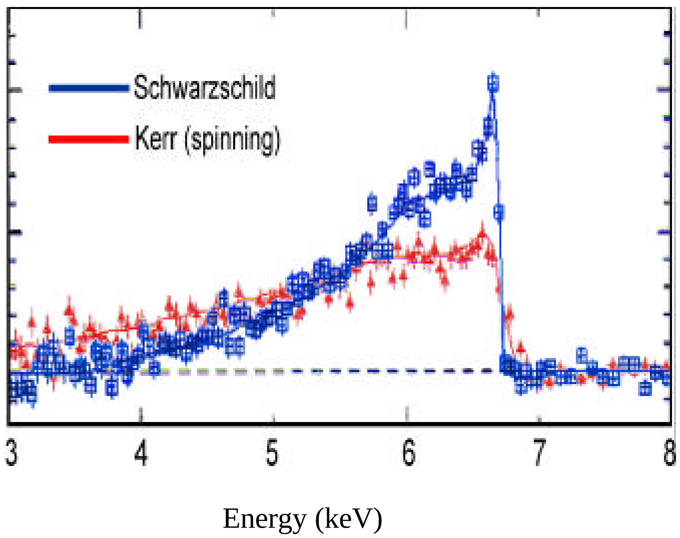
Chandra Finds Black Holes Are Everywhere!

Chandra deep field has revealed what may be some of the most distant objects ever observed

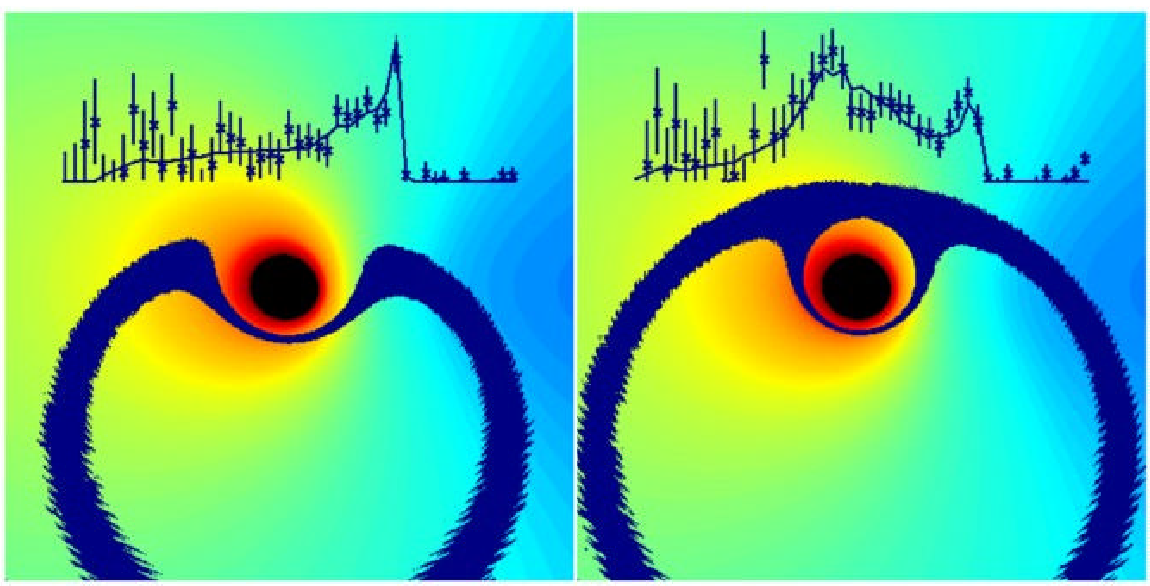


Constellation-X will obtain high resolution spectra of these faintest X-ray sources to determine redshift and source conditions

Probing Black Holes

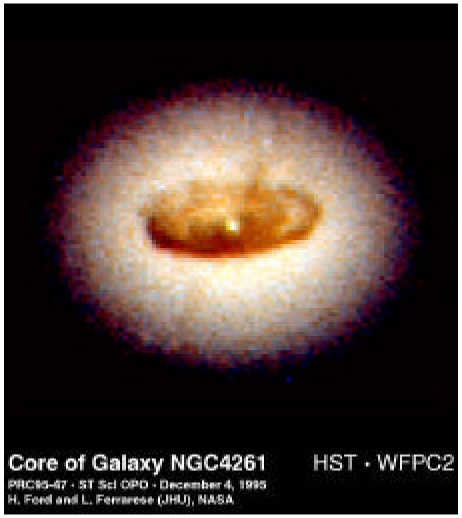


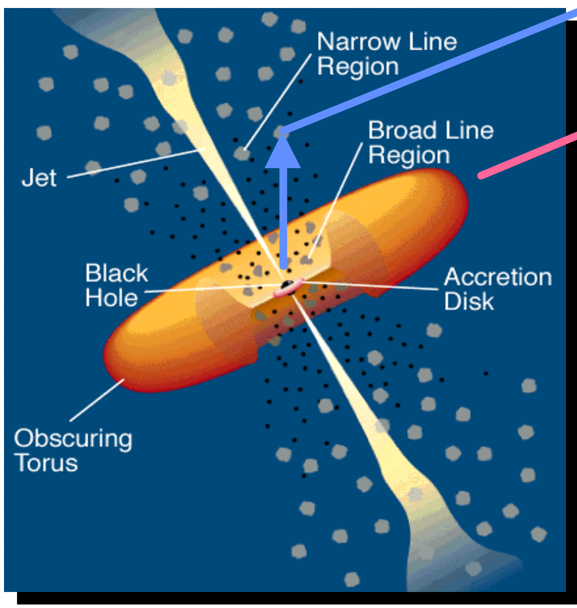
- **Constellation-X will probe close to the event horizon with 100 times better sensitivity than before**
  - Observe iron profile from close to the event horizon where strong gravity effects of General Relativity are seen
  - Investigate evolution of black hole properties by determining spin and mass over a wide range of luminosity and redshift



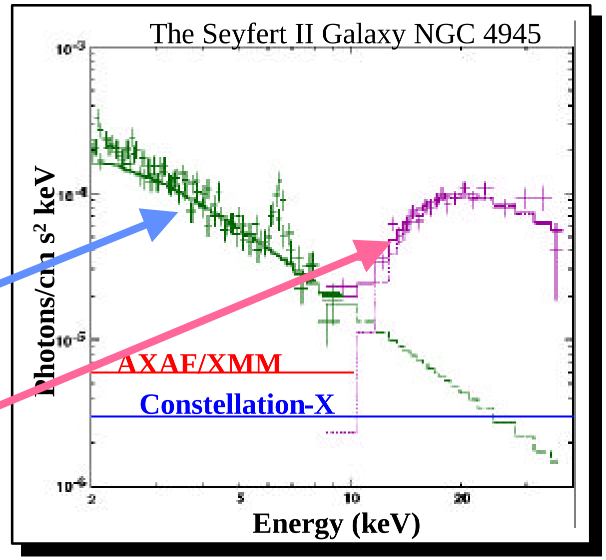
Simulated images of the region close to the event horizon illustrate the wavefront of a flare erupting above material spiralling into the black hole. The two spectra (1000 seconds apart) show substantial distortions due to GR effects.

Hidden Black Holes





Many black holes may be hidden behind an inner torus or thick disk of material



Only visible above 10 keV where current missions have poor sensitivity

Constellation-X will use multi-layer coatings on focusing optics to increase sensitivity at 40 keV by >100 over Rossi XTE

Constellation-X Requirements Flow Down

Science Goals

- **Parameters of Supermassive Black Holes**
- **Search for Dark Matter**
- **Investigate Faint Sources**
- **Plasma Diagnostics from Stars to Clusters**

Measurement Capabilities

Effective area:
15,000 cm² at 1 keV
6,000 cm² at 6.4 keV
1,500 cm² at 40 keV

Band pass:
0.25 to 40 keV

Spectral resolving power (E/DE):
≥ 300 from 0.25 to 6.0 keV
≥ 3000 at 6 keV
≥ 10 at 40 keV

System angular resolution and FOV:
15 arc sec HPD and
FOV > 2.5' (0.25 to 10 keV)

1 arc min HPD and
FOV > 8' (10 to 40 keV)

Engineering Implications

Effective area:
- Light weight, highly nested, large diameter (1.6 m) optics
- Long focal length (8-10 m)

Band pass:
- 2 types of telescopes to cover energy range

Spectral resolving power:
- Dispersive *and* non-dispersive capability to cover energy band

System angular resolution and FOV:
- Tight tolerances on telescope figure, surface finish, alignment
- ≥ 30 x 30 array for x-ray calorimeter (pixels ~5")
- Cryocooler driven by array size and readout electronics

Key Technologies

High throughput optics:
- High performance replicated shells and segments
- High reflectance coatings
- High strength/mass materials for optical surfaces

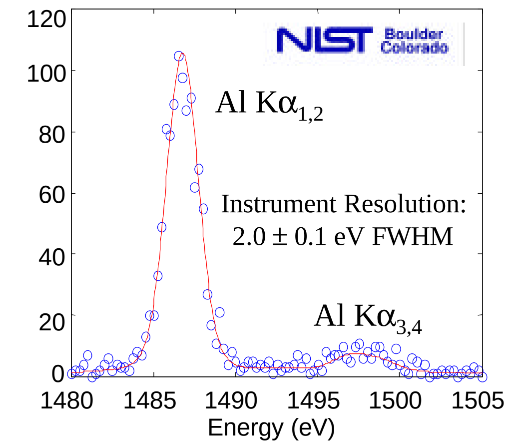
High energy band:
- Multilayer optics
- CdZnTe detectors

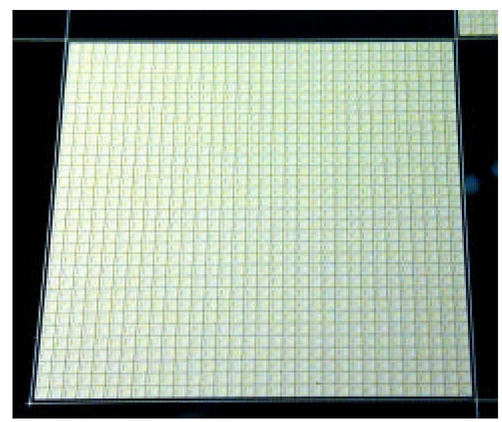
High spectral resolution:
- 2 eV calorimeter arrays
- Coolers
- Lightweight gratings
- CCD arrays extending to 0.25 keV

Optical bench:
- Stable (time and temp.)
- High strength/low weight materials

X-ray Calorimeters

- **Requirement: 2 eV FWHM energy resolution from 1 to 6 keV at 1000 counts/s/pixel in 32 x 32 pixel array**
- **Parallel Approach: Transition Edge Sensor (TES) and NTD/Ge Calorimeters**
- **Progress:**
  - Achieved 2.0 eV at 1.5 keV for Al/Ag TES with Bi absorber
  - Achieved 3.7 eV at 3.3 keV for fully microfabricated Mo/Au TES without absorber
  - Achieved 4.5 eV at 6.0 keV for fully microfabricated Mo/Cu TES without absorber
  - Demonstrated absorber scheme for fully monolithic 32 × 32 arrays of TES calorimeters
  - Completed design of photolithographic mask set for testing components critical for large TES arrays
- **Plans:**
  - Continue to fabricate single pixel detectors with a range of parameters for higher resolution performance
  - Establish integrated TES array processing
  - Fabricate small, functional TES arrays (e.g., 3 × 3)
- **Partners: GSFC, NIST, SAO, UW, LLNL, Stanford**





32 × 32 array of Bi absorbers with 97% filling factor

Cryocooler Requirements

- Cooling Power: 7.5 mW @6K, Goal 5mW @4K

  & 200mW @ 18K

- Electrical Power: 28 VDC ~ 100 Watts
- Lifetime: 5 Yrs. With goal of 10Yrs
- Heat Rejection: ~100 Watts @ 220 to 300K

  Intermediate Heat rejection @>100K

- Magnetics: Squid Detectors are sensitive to fields
- Flight Schedule: Unit#1 1Q07

  Unit#2 3Q07

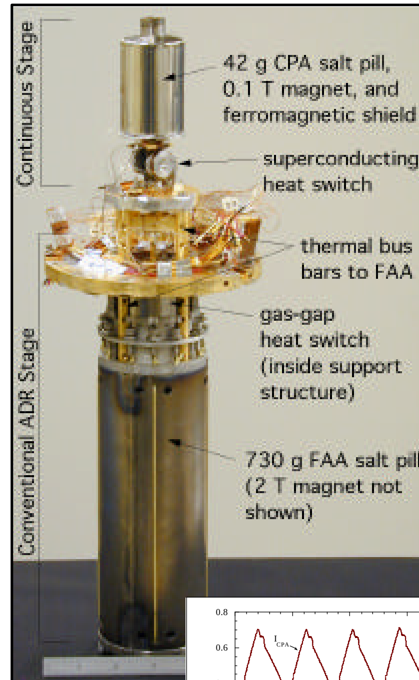
  Unit#3 1Q08

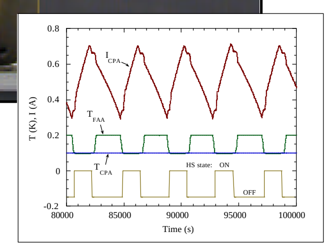
  Unit#4 3Q08

Cooling System for X-ray Calorimeter

- **Requirement: Long life cooling system that provide 40 to 65 milli Kelvin at X-ray calorimeter**
- **Approach: Sub10-Kelvin mechanical cooler to provide heat sink to sub-Kelvin Adiabatic Demagnetization Refrigerator (ADR)**
- **ADR Progress:**
  – Successfully demonstrated continuous cooling at 100 milli Kelvin
  – Began development of a 1 to 10 Kelvin stage and a liquid gap heat switch
- **Mechanical Cooler Progress:**
  – 70 K turbo Brayton cooler in acceptance test for next HST servicing mission
  – Acquisition of 6-8 K cryo cooler technology is underway and SOW reflects the requirement of NGST/TPF/Constellation-X

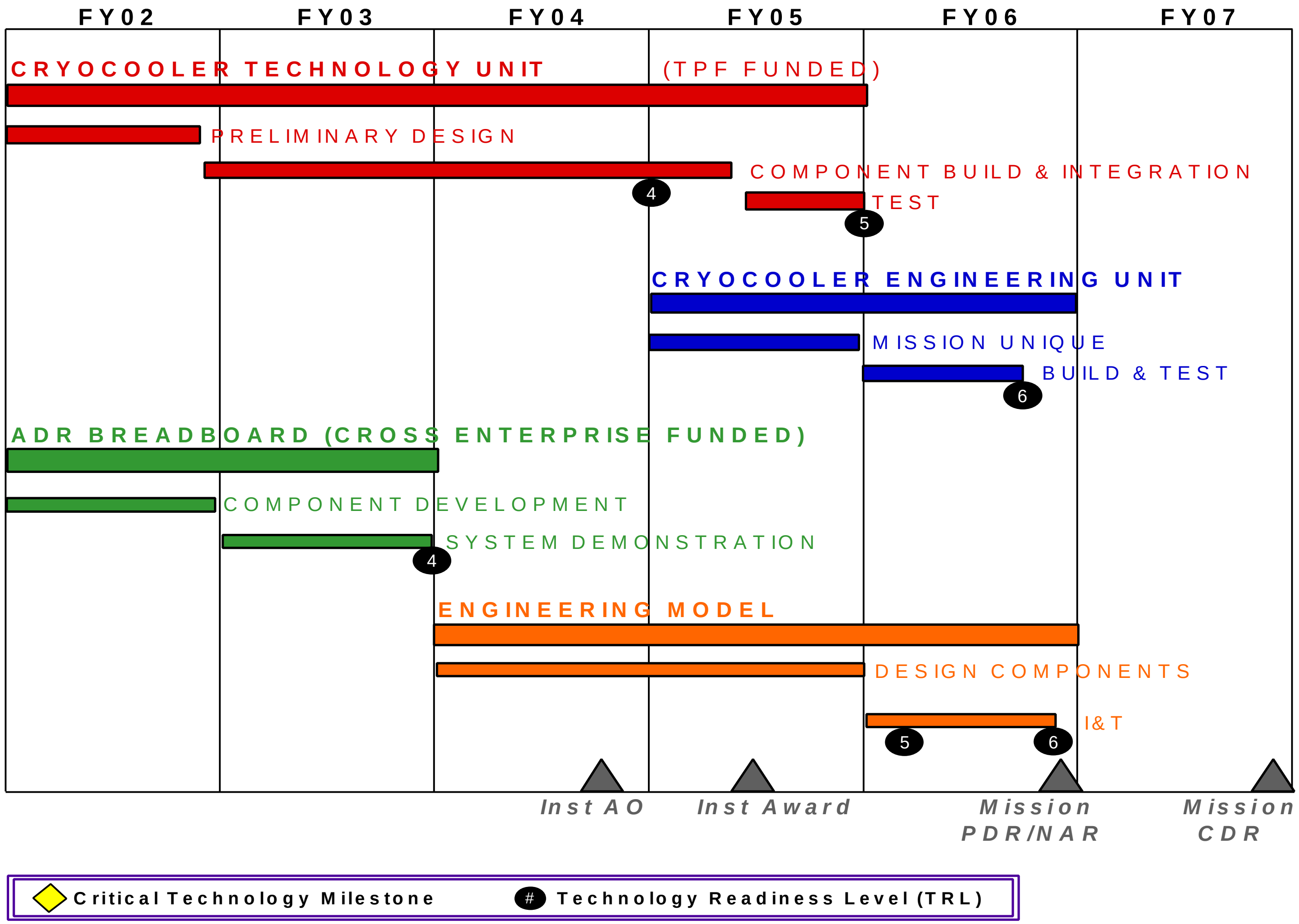
2-Stage Continuous ADR





- **Partnership: GSFC, JPL, Creare, Energen, Houston U., Berkley**

Cryocooler and ADR Technology Roadmap

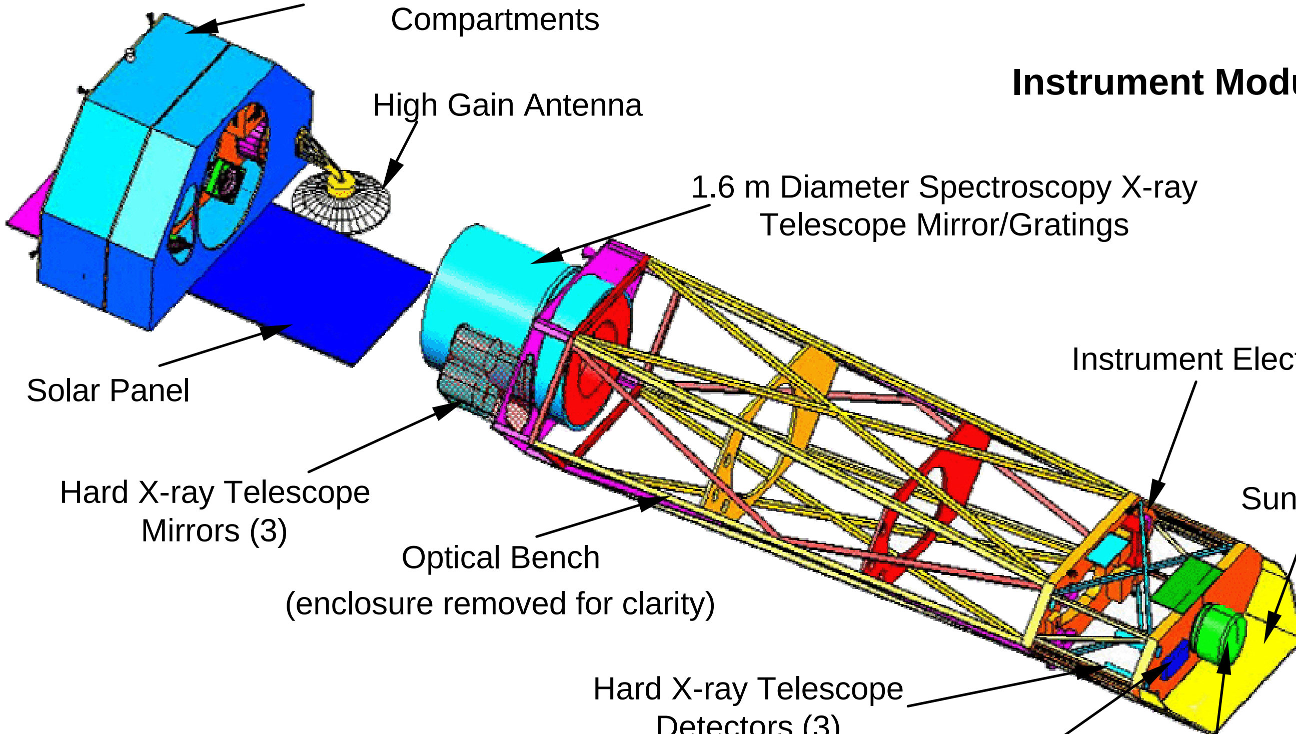


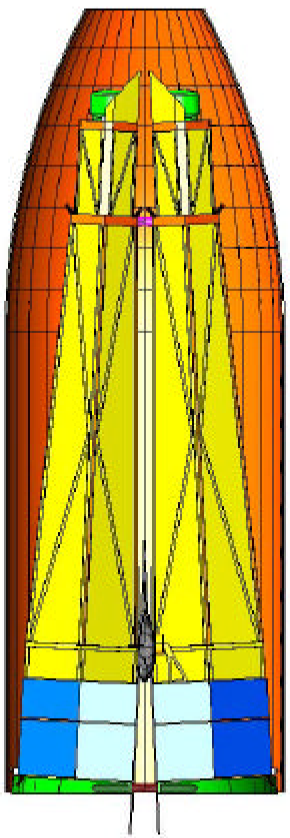
Oct 29, 2001— Rev 1 (draft)

Fixed Bench Option

Spacecraft Module

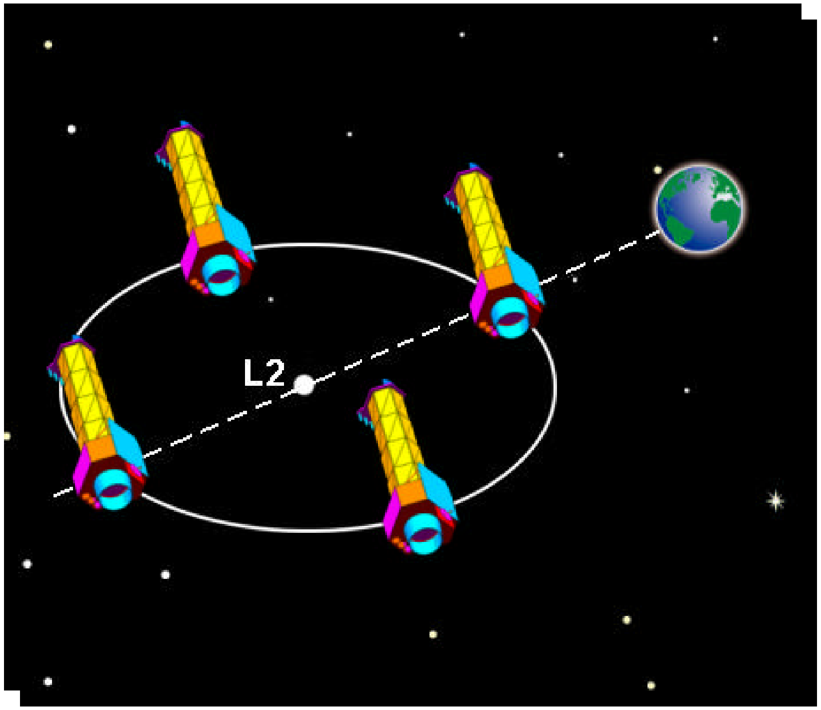
Instrument Module





Launch Configuration

Constellation-X Mission Concept



- **A multiple satellite approach:**
  - A constellation of multiple identical satellites
  - Each satellite carries a portion of the total effective area
  - Design reduces risk from any unexpected failure

- **Deep space (L2) orbit allows:**
  - High observing efficiency
  - Simultaneous viewing

- **Reference configuration:**
  - Four satellites, launched two at a time on Atlas V class vehicle
  - Extendible or fixed optical bench provides a focal length of 10 m
  - Modular design allows:
    - > Parallel development and integration of instrument module and spacecraft bus
    - > Low cost standard bus architecture and components

Summary

- Chandra and Constellation-X observations are demonstrating use of X-ray spectra for observing the black holes etc.
- Constellation-X X-ray detectors need cryocooling for high throughput, high spectral resolution observations – next major objective in X-ray astronomy.
- Constellation-X needs a EM and four Flight Units of Cryocoolers.
- Radiator Temperature >100K and low magnetic fields are value to the project.
- Mission can be ready for a 2007 new start; 2010 – 2011 launch, thus providing for timely transition and continuity in high quality X-ray observations.

Terrestrial Planet Finder (TPF)

Presented by

Dan Coulter
Project Manager
Jet Propulsion Laboratory
California Institute of Technology

November 15, 2001

What the Scientific Community Thinks About TPF

"The Terrestrial Planet Finder is the most ambitious science mission ever attempted by NASA."

"TPF will revolutionize major areas of both planetary and nonplanetary science."

- from the National Research Council's Report, *Astronomy and Astrophysics in the New Millennium*.

What is TPF All About?

Primary Goal

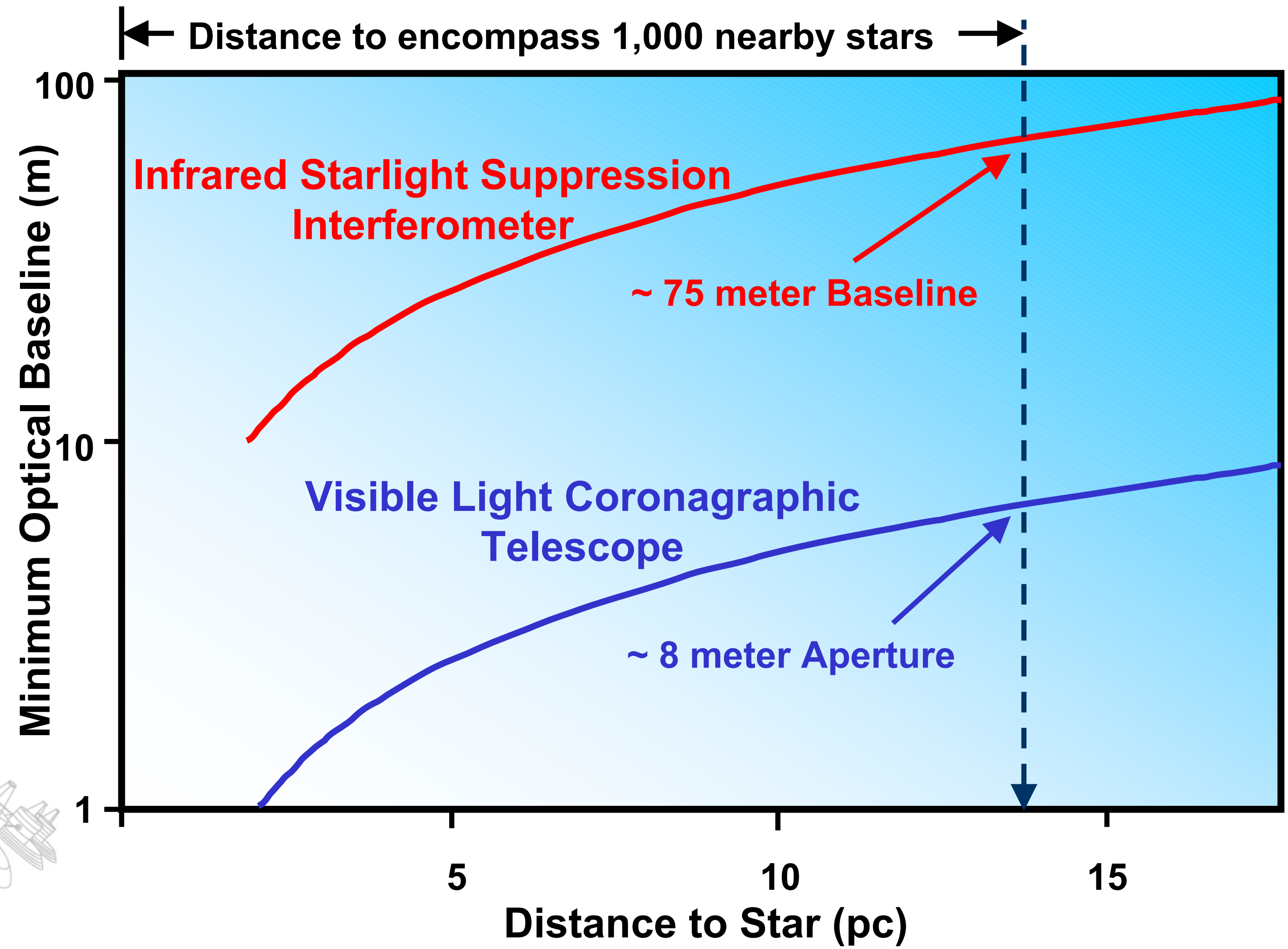
- Direct detection of *emitted* or *reflected* radiation from Earth-like planets located in the habitable zones of nearby solar type stars.
  - Determine orbital and physical properties (e.g., temperature, brightness, size, etc)
  - Spectral characterization of atmospheres and search for bio-markers

The Broader Scientific Context

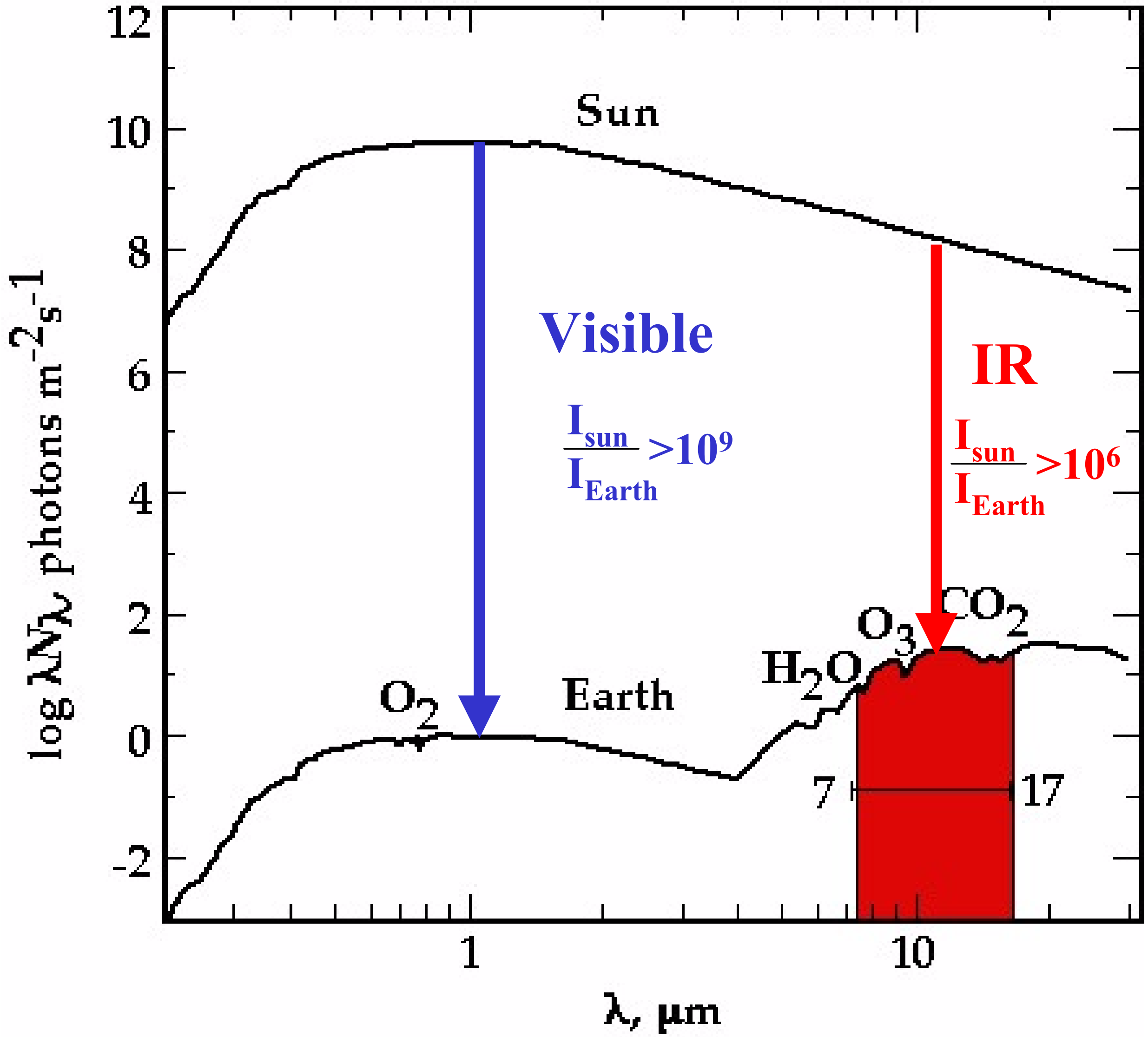
- Comparative Planetology
  - Understand properties of all planetary system constituents, e.g. both gas giant and terrestrial planets, and debris disks.
    - Determine orbital and physical properties of gas giants and debris disks
    - Provide data for refinement and validation of planetary system models
- Astrophysics
  - An observatory with the power to detect an Earth orbiting a nearby star will be able to collect important new data on many targets of general astrophysical interest.

What's So Hard About Finding Planets Anyway?

Planets are close to their parent stars!



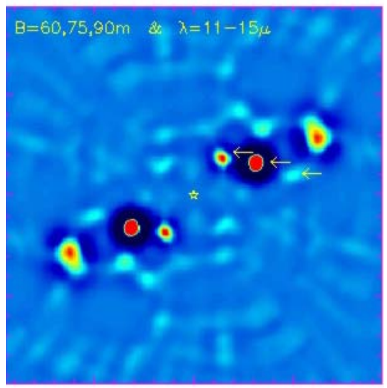
What's So Hard About Finding Planets Anyway?
Planets are dim compared to their parent stars!



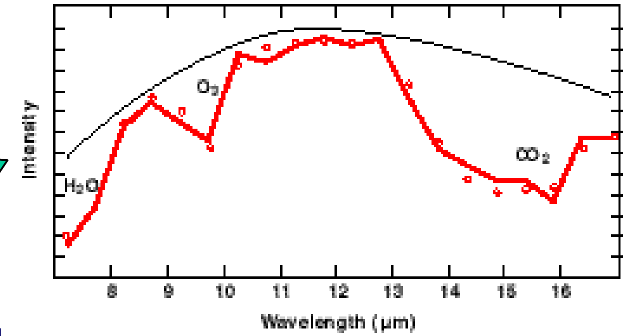
Emitted Light or Reflected Light?

- TPF will directly detect and characterize Earth-like exo-planets

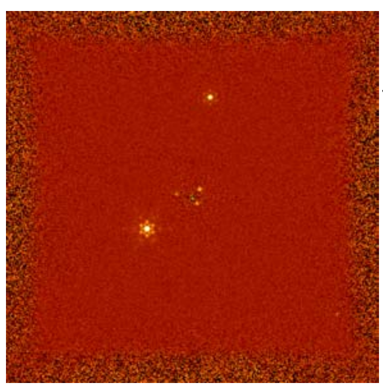
IR Nulling Interferometer Reconstruction of Venus/Earth/Mars System at 10pc



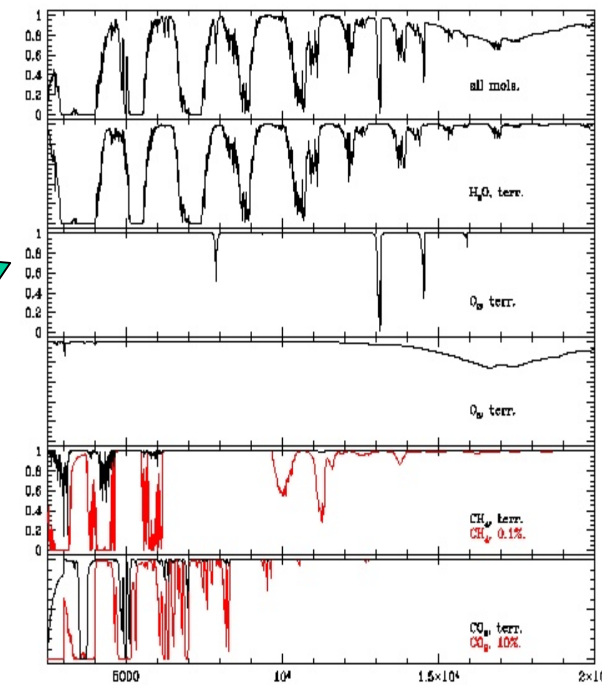
Emitted Mid-IR Light from the Planet



Visible Coronagraph Image of our Solar System at 10pc



Reflected VIS-NIR Light from the Planet



2.0 μm 1.0 0.67 0.5

Current Major TPF Activities

- Pre-Phase A Architecture Studies
  - Comprehensive Science/Architecture trade studies in progress
    - Ball Aerospace – Boulder, CO
    - Lockheed-Martin – Sunnyvale, CA
    - Boeing-SVS, Inc.– Albuquerque. NM
    - TRW – Redondo Beach, CA
  - Studies to be completed and documented in early 2002
  - Plan to select most promising mission architectures for focussed technology development

- Technology Development
  - Currently low level efforts on key technologies
  - NASA plans to substantially increase technology funding for TPF over the next 3 years to facilitate final mission architecture selection

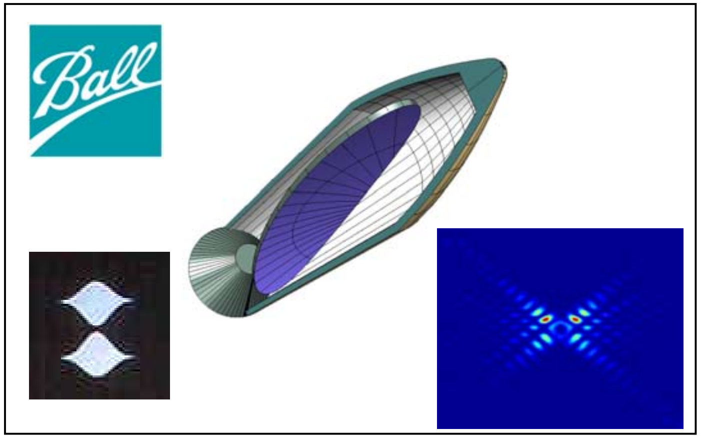
TPF Architecture Studies- Phase 1

- The first phase of the TPF Pre-Phase A Architectures Studies was completed in December, 2000.
- Four industry/academia teams evaluated ≥30 concepts to perform the TPF science
    - IR nulling interferometers
        - Separated S/C, structurally connected, tethered
    - Visible coronagraphs/apodized telescopes
        - Circular/elliptical, square/rectangular, shaped apertures
    - Out of the box concepts
        - Hyper-telescopes, Large(20m-30m) Aperture IR telescopes/coronagraphs, Fresnel coronagraph, Free-Flying Occulter, others
    - Possible Pathfinders for science and technology
        - Interferometers and coronagraphs capable of studying Jupiters
  - TPF Advisory Group Recommendations for Phase 2 study
    - Careful study of IR nulling interferometers and visible coronagraphs/apodized telescopes required
    - Study of hyper-telescopes, IR coronagraphs, Fresnel coronagraph and free-flying occulter desirable
    - Science and technology precursor mission options should be carefully considered

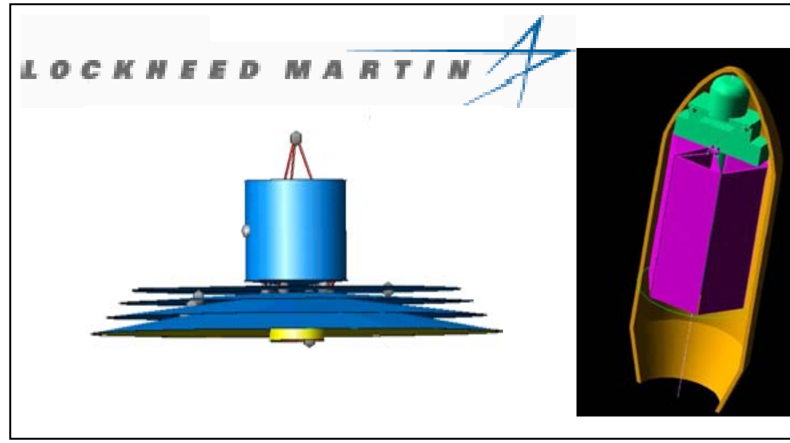
TPF Architecture Studies- Phase 2

- Each team is studying one candidate architecture option in detail in Phase 2
- Architecture concepts will be evaluated with respect to:
  - Performance relative to the planetary detection science requirements
  - Additional astrophysical science opportunities
  - Technology requirements and their feasibility
  - Life-cycle cost
  - Risk
  - Reliability/robustness
  - Science and Technology legacy that they provide for future planet detection and characterization missions
  - Potential for precursor missions relevant to the required science and technology
- Phase 2 Studies to wrap up next month with Final Pre-Phase A Architecture Study Review
- TPF Science Working Group and Technology Panel will provide recommendations to the TPF Project on the merits of the candidate architectures
- The TPF Project will select candidate architectures for future study and technology development.

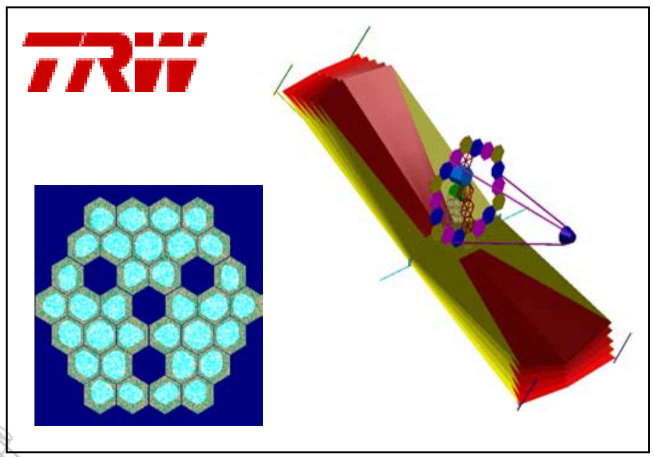
TPF Architecture Concepts



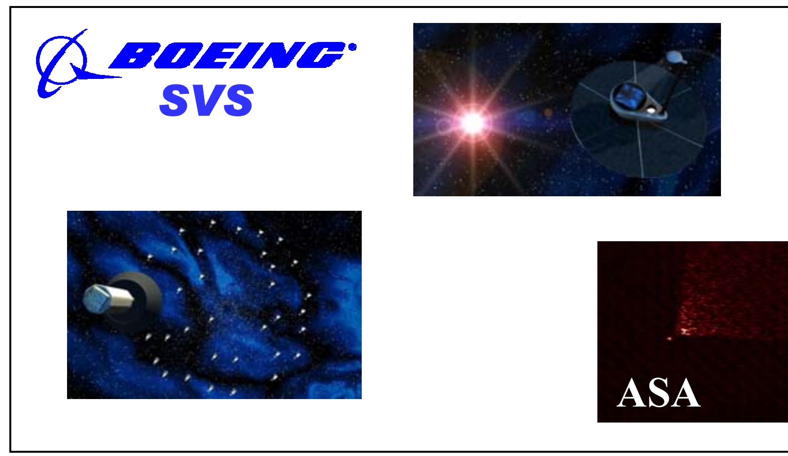
Spergel Variable-Pupil Coronagraph



IR Nulling Interferometers



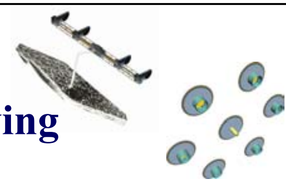
Large Aperture IR Coronagraph



Hyper-telescope

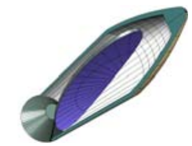
TPF Technology Enablers for Specific Architectures

IR Interferometers



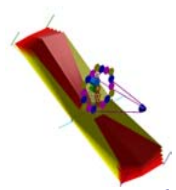
- Precision formation flying (separated s/c systems)
- Cryogenic achromatic nulling to $\geq 10^6$
- Low vibration cryo-coolers (4-6K)
- Cryogenic opto-mechanics

Visible Coronagraphs



- Large lightweight optics
- High Contrast imaging to $\geq 10^9$
  - Apodization & coronagraphy
- Wavefront Sensing and Control

IR Coronagraphs

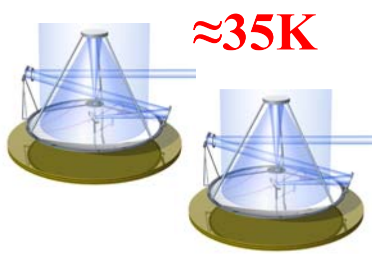


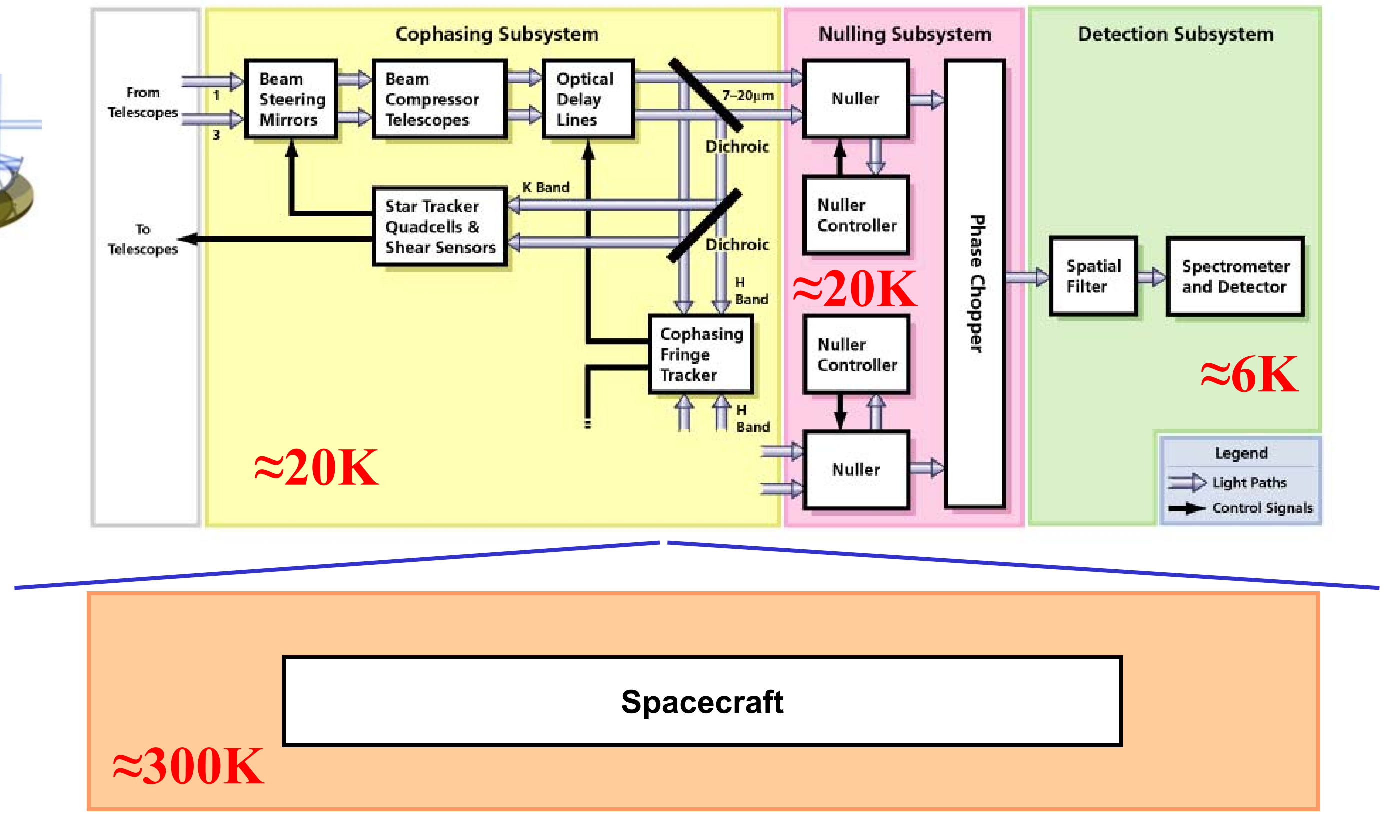
- Large lightweight cryogenic optics
- High Contrast imaging to $\geq 10^6$
  - Apodization & coronagraphy
- Wavefront Sensing and Control
- Low vibration cryo-coolers (4-6K)
- Cryogenic opto-mechanics

Hyper-Telescope

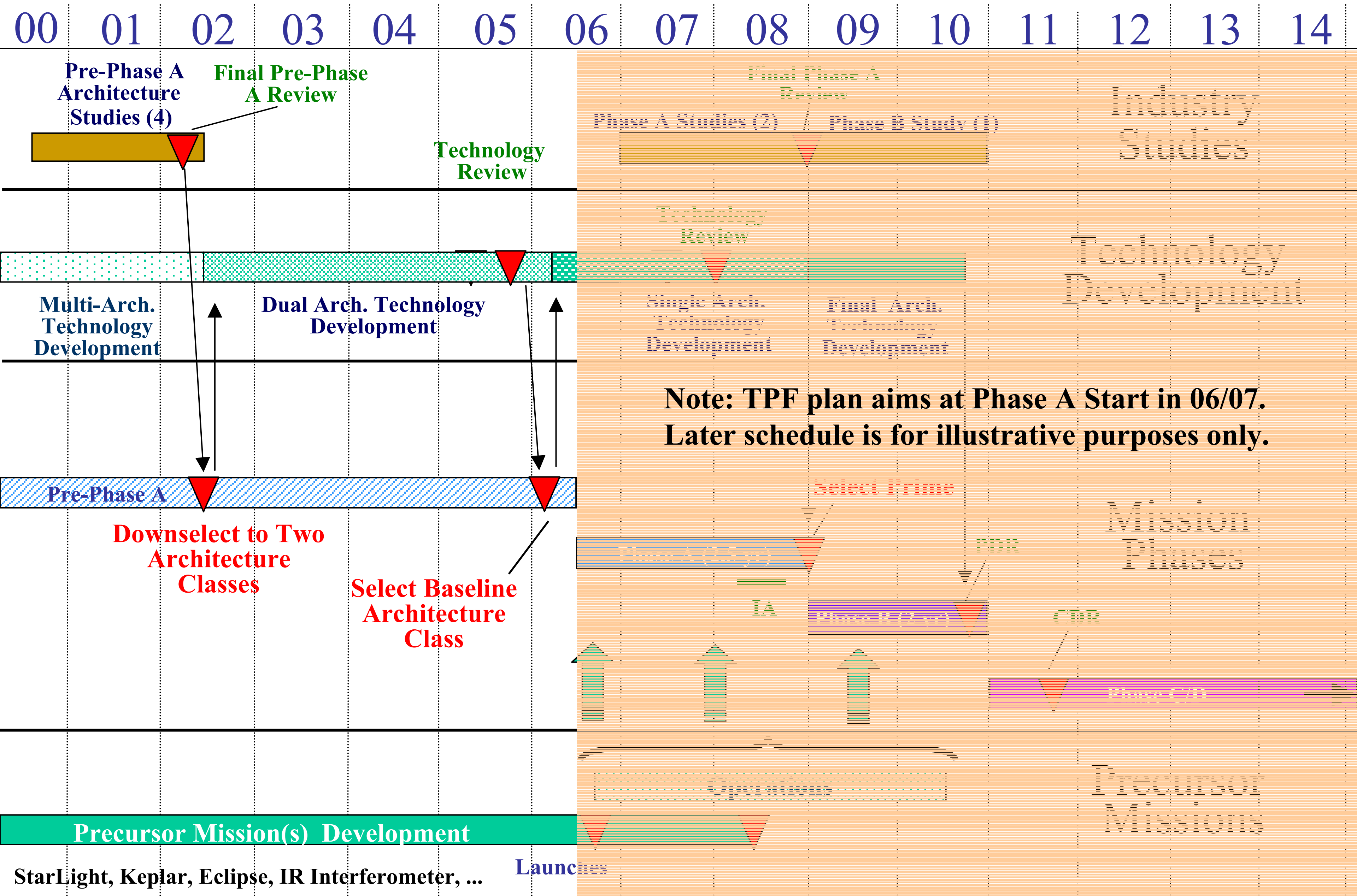
- Precision formation flying
- High Contrast imaging to $\geq 10^9$
- Wavefront Sensing and Control

TPF Thermal System "Design Concept" for Nulling Interferometer Architecture





TPF Schedule



Summary

- TPF is the most ambitious science mission ever attempted by NASA- from *Astronomy and Astrophysics in the New Millennium*.
- Terrestrial planet detection and characterization is hard!
  - Planets are near their parent stars
  - Planets are dim compared to their parent stars
- Several mission architectures may be viable
  - None are proven to date
- TPF is entering a period of aggressive technology development to validate key technologies for candidate architectures
  - Results will facilitate final architecture selection
  - Reliable, low vibration, long life cryocoolers are critical to IR architectures

Terrestrial Planet Finder

TPF

A NASA Origins Mission